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DISCRETE-PHASE METHOD FOR THE NONCONTACT MEASUREMENT OF TURBINE--ETC(U)
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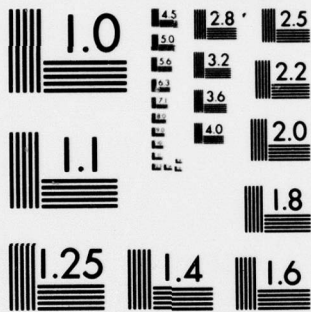
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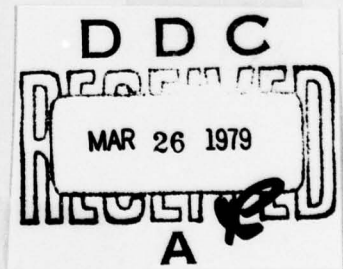
FOREIGN TECHNOLOGY DIVISION



DISCRETE-PHASE METHOD FOR THE NONCONTACT
MEASUREMENT OF TURBINE BLADE
MEASUREMENTS

by

I. Ye. Zablotskiy and Yu. A. Korostelev



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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З э	<i>З э</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ë in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh ⁻¹
cos	cos	ch	cosh	arc ch	cosh ⁻¹
tg	tan	th	tanh	arc th	tanh ⁻¹
ctg	cot	cth	coth	arc cth	coth ⁻¹
sec	sec	sch	sech	arc sch	sech ⁻¹
cosec	csc	csch	csch	arc csch	csch ⁻¹
		Russian	English		
		rot	curl		
		lg	log		

DISCRETE-PHASE METHOD FOR THE NONCONTACT MEASUREMENT OF TURBINE BLADE MEASUREMENTS

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Candidates of Technical Sciences

At the present time the basic method for the measurement of blade vibrations is subjecting them to strain measurement. Nevertheless, strain measurement has a number of serious shortcomings, one of which is the limited number of blades which can be checked at the same time. As an example, many years of experience show that in axial compressors the stresses in the different rotor blades in the case of forced vibrations can differ from each other by 3-4 times, and in the case of self-excited vibrations even by 10-12 times. With such high spreads the reliability in the determination of the maximum vibration-strain in a unit based on the results of strain measurement of 10-20% of the rotor blades is not great. Another serious shortcoming of strain measurement is the short lifetime of the strain gages, conductors and slip rings, which leads to a strong "stretching out" of the tests in time as a result of the frequent reassembly of the machines for the reestablishment of sensors, replacement of the slip ring, and in the case of a limited time and impossibility of reassembly the inadequate number of tests which are carried out.

In addition to these basic shortcomings, it is also possible to point out, for example, the complexity of strain measurement of compressors of high pressure cascades on multicascade turbocompressor engines, the great amount of work involved in the preparation of the strain gages, the need for structural changes in the machine for installation of the slip ring, which cannot always be made, the complexity of strain measurement of aircraft engines under flight conditions, etc.

All these shortcomings forced the search for new methods of measurement, primarily the so-called noncontact methods, i.e., not connected with the necessity of locating the sensors on rotating parts.

Thus the English firm "Bristol Siddeley" has developed and is making wide use of a method of measurement with the help of a cascade with frequency modulation [1]. The idea of it amounts to the following. In the turbine housing above the rotor blades a zigzag conductor is mounted which has a pitch of approximately 2° in the arc of the circumference which is strictly maintained. Into the face of the blade a magnet is pressed, which in the case of intersection of the turns of the conductor induces in it a variable electrical signal with a frequency which is equal to the number of windings, multiplied by the number of revolutions. In the case of vibrations of the blade the signal is modulated in frequency. The depth of modulation is proportional to the velocity of the blade tip in its vibrational movement, i.e., the product of the amplitude of shifting by the frequency of vibrations Af . As confirmed by E. K. Armstrong [2], the parameter Af is very convenient for determining the degree of vibration stress of blades, since the fatigue limit, defined in Af units, for blades of the most diverse configuration has practically no dependence on the form of the vibrations. The firm has been using the described method for around 10 years mainly for measuring the vibrations of blades of the second stages of two stage engines. Usually on each stage it is possible to mount two-three cascades, and thus to check two-three blades on each wheel. The shortcomings of this method are the small (even

less than with strain measurement) number of blades which are checked, complexity of preparation, and temperature limitations.

Attempts are being made at the detection and rough evaluation of the vibrations of blades based on the nature of the noise which is given off by the vibrating blades. However, the separation of the noise of the vibrations of the blades from the general spectrum of noises of the engine turns out to be so complex that this method does not have wide application.

Evidently for obtaining information about the behavior of all, or at least the majority, of the rotor blades it is necessary to compress the information channel in order to avoid a large amount of measuring and recording equipment. One of such methods of compression can be the quantization in time, which is used widely in telemetry, of the signal which characterizes the magnitude being measured.

It is precisely this idea which is the basis of the discrete-phase method of measuring the vibrations of blades, the essence of which is reduced to the fact that the measurement is not carried out continuously, but only at the moment of passage of the blade past a pair of sensors, installed rigidly in the housing of the turbine. This makes it possible to check all the rotor blades without exception.

In our country several devices have been developed which use this method of measurement. They are finding all the more application in the investigation and final adjustment of axial compressors for aircraft engines. The most widely used is the electron-beam device for the recording of amplitude of vibrations of blades (ELURA) [ЭЛУРА]*.

*Work on the development of similar devices is being carried out abroad [4-6].

The principle of operation of the ELURA device is the following. On the disk of the turbine wheel or on any other disk sitting on the same shaft with the wheel there are exciters k_1, k_2, \dots, k_z with an angular pitch equal to the pitch of the blades (Fig. 1, a). The exciters can be made in the form of steel pins, teeth-slots or

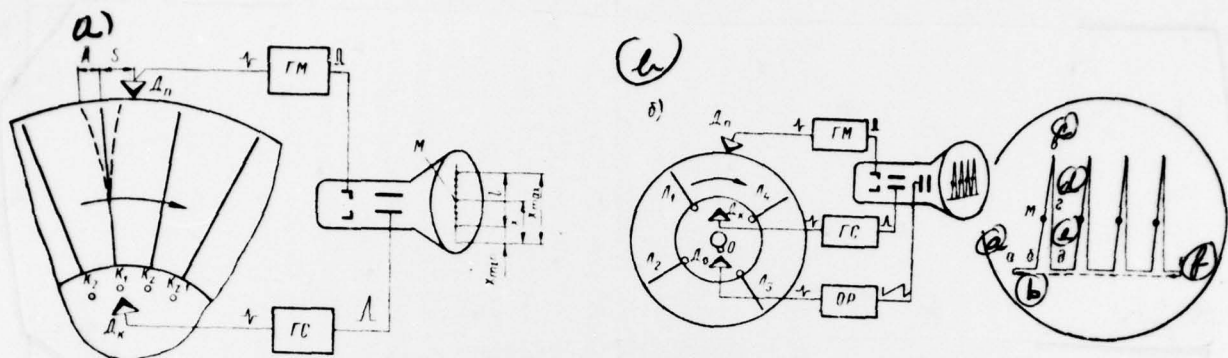


Figure 1. Arrangement for measuring the amplitude of shifts of blade tips (a) and a block-diagram of the ELURA device (b).

openings. Mounted opposite the exciters on the fixed part of the turbine is a pulse sensor D_k [A_k], generating a pulse at the moment the exciter passes it. In the housing of the turbine above the wheel there is still another sensor D_p [A_p] mounted. It generates a pulse at the moment that the blade tip passes it.

The pulse from sensor D_k triggers the braked sawtooth-voltage generator (line generator GS [GC]). The signal from the output of the generator is fed to the vertical deflector plates of the electron-beam tube, forcing the beam to be shifted at a constant rate over the screen and to draw a vertical line-row.

The signal from sensor D_p is shaped into a short positive pulse by the mark pulse generator GM [GM] and is fed to the modulator of the electron-beam tube, intensifying at this moment the brightness of luminescence of the beam. As a result, at the moment the blade tip passes the sensor D_p a bright point-mark M appears on the line.

The distance x from the beginning of the row to the mark is proportional to the time interval τ between the pulses of the sensors D_k and D_p

$$x = V_e \tau,$$

(1)

where V_c - rate of movement of the beam over the screen.

In turn the time interval τ is proportional to the path S which the blade tip should cover up to sensor D_p , after the exciter k has moved past sensor D_k

$$\tau = \frac{S}{u_k}, \quad (2)$$

where u_k - tip speed of the blade tip.

Substituting τ from expression (2) into expression (1), we obtain*

$$x = \frac{V_c}{u_k} S. \quad (3)$$

*Here and everywhere subsequently a simplified mathematical description of the method is given.

Let us assume that on the wheel there is only one exciter and one blade. If the blade does not vibrate, the distance S with each revolution of the wheel is the same, and at a constant rate of rotation the mark will appear at the same distance from the beginning of the row.

If in the case of vibrations with each revolution the blade approaches the sensors with different displacement, the marks will appear at different distances from the beginning of the row, and the extreme right position of the blade will correspond to the minimum distance to the mark x_{\min} , and the extreme left - to the maximum - x_{\max} .

Marks corresponding to an intermediate position of the blade are located within this range, forming a clear line, the length of which

$$l = (x_{\max} - x_{\min}) = \frac{V_c}{u_k} 2A. \quad (4)$$

Thus, knowing the rate of movement of the beam V_c and the tip speed of the wheel u_k , based on the length of the bright line it is possible to determine the amplitude of vibrations of the blade tip.

In the ELURA-3M device the line generator is made in such a way that the rate of movement of the beam changes in proportion to the number of revolutions of the wheel, therefore with a change of revolutions the scale of the image remains constant

$$\frac{V_c}{u_k} = M_c = \text{const.} \quad (5)$$

Everything stated above is valid if the blade, with each revolution of the wheel, arrives at the sensors in different phases, i.e., if the frequency of vibrations is not a multiple to the number of revolutions. In the case of precise multiplicity, the method in the form as it is described here is not suitable. Here it is important to note that measurement is impossible only in the case of precise multiplicity of the frequency of vibrations and the number of revolutions, since any, even very small, deviation from multiplicity leads to a change in the phase of vibrations at the point where the sensors are installed. A case of precise multiplicity is possible only when there is a bond between the frequency of vibrations and the number of revolutions of the wheel. Vibrations of the blades at a frequency, connected with the number of revolutions, is observed in the case of forced vibrations when they are excited by a fixed irregularity of flow. Forced vibrations with excitation from a rotating disruption, self-excited vibrations, vibrations of the buffeting type, and others occur with frequencies which are not connected with the number of revolutions (usually this is one of the natural frequencies of the blade), and their amplitudes can be measured as described above. The method of measurement of vibrations with a frequency which is a multiple to the number of revolutions has certain special features which will not be considered here.

For the separation of information which is arriving over the sensor-instrument communication channel from the different blades of the wheel a second, horizontal movement of the beam over the screen is provided. This movement is realized by a second generator of sawtooth voltage OR [OP], operating in the mode of continuous

tracking (Figure 1,b). Synchronization of the generator is realized by yet another pulse sensor D_0 [A_0], generating one pulse per revolution at the moment that exciter 0 (pins or slots), located on the rotor of the turbine, moves past it.

The movement of the beam from left to right (sector a) begins after the appearance of the pulse from sensor D_0 . After a certain time exciter k approaches the sensor D_k and the row generator is triggered, forcing the beam to shift in a vertical direction (sector b), forming the first row. When the tip of the blade passes the sensor D_p a mark appears on the row. This mark fixes the position of the blade L_1 [A_1] (point M). Further the beam completes the movement upward (sector c), returns to the initial position (sector d) rapidly, and continues movement in a horizontal position (sector e) until the appearance of the following pulse from sensor D_k . Again the exciter k and the blade L_1 approach the sensors D_k and D_p . And again the first row appears with a mark corresponding to this blade and the cycle is repeated. Thus each row of the image on the screen corresponds to a specific blade of the wheel, and the conformity of the numbers of the blade and the row is determined uniquely by the mutual position of the sensors D_p and D_0 .

As a result the image has the form shown in Figure 2. Lined drawings are made from photographs of the screen of the ELURA-3M device in the absence (Fig. 2,a) and in the presence (Fig. 2,b) of vibrations on the wheel of a compressor which has 25 blades. The lines represented in the drawing during photographing are usually increased for improving the clarity of representation of the marks. The row of points located above the horizontal scale are the revolution marks, realized by the second beam of the tube. Based on the number of these points on the length of the screen it is possible to determine the number of revolutions of the wheel. For convenience of interpretation the screen is equipped with horizontal and vertical scales with millimeter divisions and an image scale indicator (figures below). In the photograph (Figure 2,b) developed self-excited vibrations of the first form are depicted. The maximum amplitude in the set (5th blade from the right) comprises ~ 2 mm, while the minimum (10th blade from the right) - does not exceed

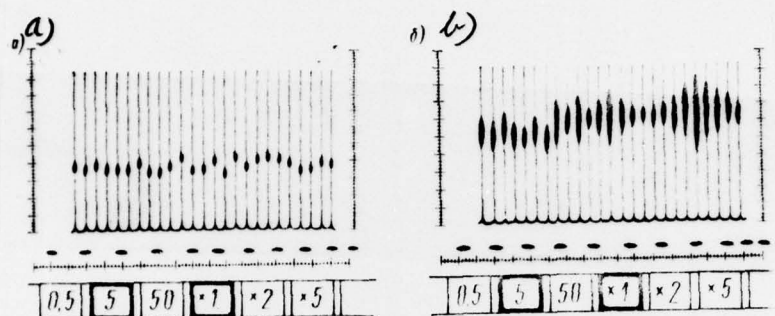


Figure 2. Photographs from the screen of the ELURA-3 device:
a - no vibrations; b - vibrations present.

Figures below - scale of measurement; lower row of points - marks of revolutions.

0.3 mm. The shifting of the centers of the bright lines is explained by the difference in the pitches of the blades and the exciters, and partially by the different static deformation of the blades.

A photograph of the ELURA-3 device is given on the first page of the cover of the journal.

The many years of experience of operation of a series of ELURA-3 devices showed that this method of measurement supplements significantly, and in a number of cases even replaces strain gage measurement completely, making it possible not only to measure the amplitude of shifts of blade tips, but also other parameters of vibrations.

Having both operating sensors D_k and D_p in the housing above the wheel in one plane of rotation (Fig. 3,a), it is possible to measure the amplitudes of the speeds of the blade tips in their vibratory motion, i.e., the product Af . This makes it possible to determine the frequency f , if amplitudes A are measured in parallel, or based on the magnitude of Af to determine vibration stresses regardless of the form of vibration [2].

For measuring the amplitude of velocity the distance between the sensors L should be somewhat less than the pitch of the blades h ($L \approx 0.8 h$). The blade, passing by the sensor D_k , triggers the

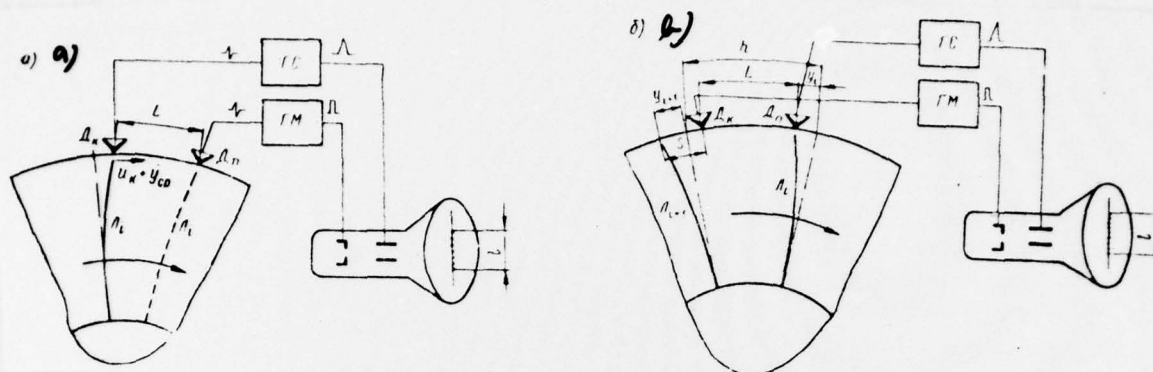


Figure 3. Arrangements for measuring the amplitudes of velocities (a) and mutual shiftings (b) of blade tips.

line generator GS, and, passing by the sensor D_p - the mark generator GM. The time interval between these events is equal to

$$\tau = \frac{L}{u_k + y}, \quad (6)$$

where y - relative velocity of the blade tip in vibrational movement on the sector $D_k - D_p$.

When there are no vibrations ($y=0$) the blade passes the base L during each revolution in the same time interval and the mark appears at the same distance from the beginning of the row. The image on the screen will have the form shown in Figure 2,a. In the case of vibrations the blade, on different revolutions arriving at the sensors in different phases, covers the base L in different intervals of time. The marks appear at different distances from the beginning of the row, forming clear lines as shown in Figure 2,b.

The length of each bright line will be proportional to the difference between the maximum and minimum time intervals

$$l = V_r (\tau_{\max} - \tau_{\min}). \quad (7)$$

But

$$\tau_{\min}^{\max} = \frac{L}{u_k + y_{\max}} \quad (8)$$

In the case of vibrations which are close to harmonic

$$\dot{y}_{\max} = \left[\frac{d}{dt} (A \sin 2\pi f t) \right]_{\max} = 2\pi A f \quad (9)$$

From expressions (7)-(9) we obtain

$$l = V_c \left[\frac{L}{u_k - 2\pi A f} - \frac{L}{u_k + 2\pi A f} \right] \approx \frac{4\pi L V_c}{u_k^2} A f \quad (10)$$

Or with a calculation of expression (5)

$$l = 4\pi L M_c \frac{A f}{u_k} \quad (11)$$

Thus the lengths of the bright lines on the screen of the device are proportional to the amplitudes of the relative velocities of vibrations of the blades.

And, finally, for determining the phase shift between the vibrations of the blades the sensors D_k and D_p are hooked up to the device as shown in Figure 3,b. Now the beginning of the row corresponds to the moment that the blade with number i passes by sensor D_k , and the appearance of the mark - to the moment that the adjoining blade $(i+1)$ passes by sensor D_p .

We write the expression for the time interval between these two events

$$\tau = \frac{S}{u_k} - \frac{h - L - y_i + y_{i+1}}{u_k}, \quad (12)$$

where y_i and y_{i+1} - deflections of the blades with numbers i and $i+1$ at the moment they pass by sensors D_k and D_p .

Substituting expression (12) into expression (1), we find the distance from the mark to the beginning of the row

$$x = M_c (h - L + y_{i+1} - y_i). \quad (13)$$

When the blades are not vibrating ($y_1 = y_2 = \dots = y_z = 0$), the marks for each revolution appear at the same distances from the beginning of the row, similar to that depicted in Figure 2,a.

When the blades are vibrating, the marks, similar to that depicted in Figure 2,b, are smeared in lines, the lengths of which in the case of synchronous vibrations are proportional to the amplitudes of the mutual shiftings of the adjacent blades

$$l = M_c B_{i, i+1} = M_c \sqrt{A_i^2 + A_{i+1}^2 - 2A_i A_{i+1} \cos \phi_{i, i+1}}, \quad (14)$$

where $\phi_{i, i+1}$ - phase shift between vibrations of the i -th and $(i+1)$ -th blades.

Having made simultaneous measurements of the amplitudes of shifts of each blade A_1, A_2, \dots, A_z and the amplitudes of their mutual shifts $B_{1,2}; B_{2,3}; \dots B_{z,1}$, it is possible to determine the phase shift between the vibrations of adjacent blades, having compiled a system of z equations (14).

Thus the discrete-phase method makes it possible to determine all the parameters of vibrations of each blade of the turbine wheel.

BIBLIOGRAPHY

1. Eccles E. S., Seymour D. G. Measuring Gas Turbine Blade Vibration. — «Engineering», London, March, 1962.
2. Armstrong E. K. Recent Blade Vibration Techniques. — «Trans. ASME», Ser. A, 1967, N 3.
3. Заблочкий И. Е., Коростелев Ю. А., Свиблов Л. Б. Устройство для бесконтактного исследования колебательного движения лопаток колеса турбомашин. Авт. свид. № 160886. — «Бюллетень изобретений», 1964, № 5.
4. Perfectionnements à la détection et à la mesure des vibrations d'aubes mobiles de turbomachines ou éléments analogues. Франц. патент. Кл. G01m, N 14172/5.
5. Способ измерения вибраций деталей на подвижном объекте. Япон. патент. Кл. H11B13, N 17558.
6. Hohenberg R. Detection and Study of Compressor Blade Vibration. — «Experimental mechanics», 1967, v. 7, N 6.
7. Заблочкий И. Е., Коростелев Ю. А., Свиблов Л. Б. Электронное учное устройство для измерения вибраций лопаток рабочего колеса турбомашин ЭЛУРА. Авт. свид. № 236827. — «Изобретения, промышленные образцы и товарные знаки», 1969, № 7.
8. Заблочкий И. Е., Коростелев Ю. А. и Свиблов Л. Б. Appareillage pour la mesure des vibrations des aubes d'une roue mobile de turbomachine. Patente en France № 1555760. — «Bulletin officiel de la propriété industrielle», 1969, N 5.
9. Заблочкий И. Е., Коростелев Ю. А., Свиблов Л. Б. Dispositivo per la misura della vibrazioni delle pale di ruote di machine a turbina. Патент в Италии № 830809, 1969.
10. Заблочкий И. Е., Коростелев Ю. А., Свиблов Л. Б. Device for Measuring Vibrations of Wheel Blades of Turbine Machines. Патент в Англии № 1147737, 1969.

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